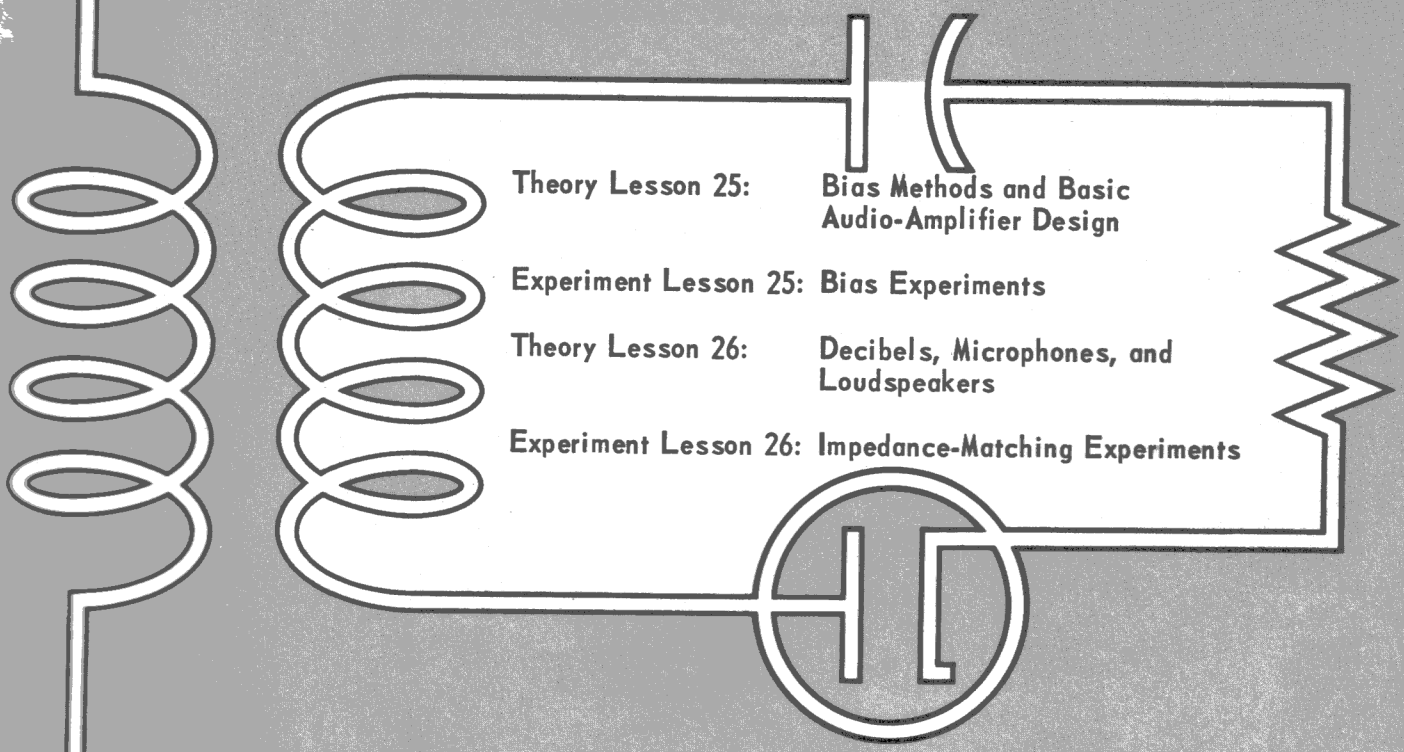
Study Group 13

ELECTRONIC FUNDAMENTALS



Theory Lesson 25:	Bias Methods and Basic Audio-Amplifier Design
Experiment Lesson 25:	Bias Experiments
Theory Lesson 26:	Decibels, Microphones, and Loudspeakers
Experiment Lesson 26:	Impedance-Matching Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York, N. Y.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 25

BIAS METHODS AND BASIC AUDIO-AMPLIFIER DESIGN

25-1. Bias Methods

25-2. Screen-Grid Voltage Supply

25-3. Selecting Other Components

25-4. Using Resistance-Coupled Amplifier Charts

25-5. Designing a Simple Two-Stage Audio Amplifier

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RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

Theory Lesson 25

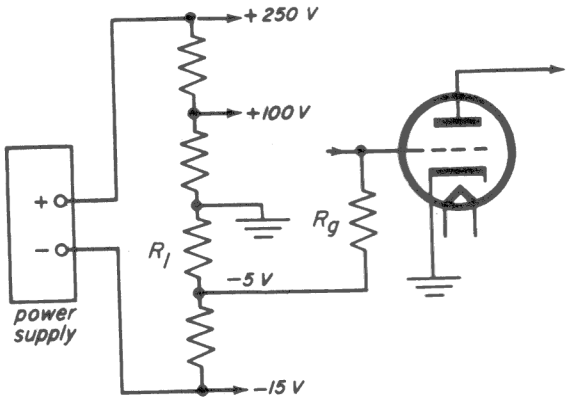
INTRODUCTION

Until now, we have used batteries to represent the different potentials that exist between the electron tube electrodes in amplifier circuits. Yet, except in the case of portable receivers, batteries are seldom used to provide these potentials. One purpose of this lesson is to show you how plate, screen, and control-grid voltages are brought to the various electrodes in practical amplifiers. You have already studied power supplies, so there is no need to tell you how B voltages are obtained. But there is some need for a discussion of methods used in obtaining C bias, and so this information will be included in this lesson.

Another purpose of this lesson is to show you how you may use the information that you have received up till now and that you will receive in this lesson to enable you to design a simple two-stage audio amplifier. This is useful information, for the same methods may be extended to the design of more complicated audio systems. Finally, it is the purpose of this lesson to show you how simple negative or degenerative feedback is applied to an audio amplifier in order to reduce hum and distortion.

25-1. BIAS METHODS

Fixed Bias. Let's start off this discussion of bias methods by talking about a source of bias voltage that has been discussed before. You recall that when you were studying power-supply voltage dividers, it was shown how negative voltages might be obtained through a tap or taps on the voltage divider (Fig. 25-1). *Fixed bias*, as it is called, may be applied to one or more tubes by means of a lead from the bias point on the voltage divider to the grid-load resistor.



fixed bias applied to a triode grid

Fig. 25-1

For example, the voltage drop across R_1 in the illustration is 5 volts. The positive end of R_1 is grounded and the negative end is tied to R_g. There is no current flowing through R_g, so the potential that exists at one end of R_g appears at the other end. With the cathode at ground potential, the difference in potential between the grid and cathode is 5 volts, with the grid negative with respect to the cathode. Thus we provide a –5-volt bias for the tube.

Self Bias. *Self bias* is what we normally call any bias voltage that is developed by the tube itself. The most common form of self bias is called *cathode* bias. In Fig. 25-2, the resistor R_k is called the cathode resistor, or, sometimes, the cathode-bias resistor. In such a circuit, the negative end

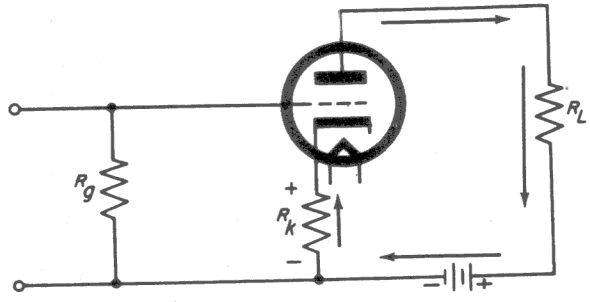


Fig. 25-2

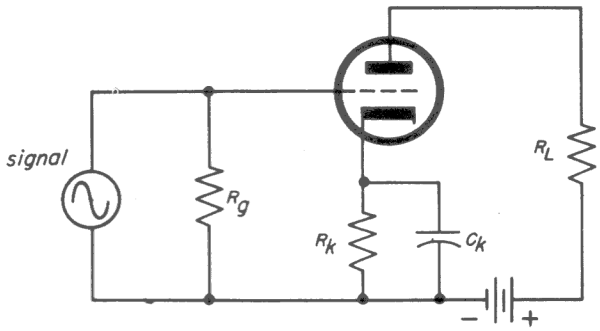


Fig. 25-3

of the B supply is connected to the grounded end of the cathode resistor. Therefore, any current flowing in the plate circuit – in other words, between cathode and plate – must flow through the cathode resistor R_k. Current flowing through a resistor produces a voltage drop. When there is no signal applied to the grid of the tube, the current is steady and the voltage drop is constant. As we know, current flows from negative to positive, so the end of R_k through which the current starts flowing is the negative end. This makes the cathode positive with respect to ground. One end of the grid resistor is grounded, so the potential difference between cathode and grid is equal to the voltage drop across R_k – with the grid being negative with respect to the cathode. The potential difference between grid and cathode will remain constant just so long as the plate current remains steady.

However, when a signal is applied to the grid, the plate current varies and the voltage drop across R_k varies. Sometimes we want this to happen but, in most cases, we want to develop a bias voltage across R_k that is steady. For that reason, we place a capacitor (C_k) across the cathode resistor (Fig. 25-3) to maintain the voltage drop across R_k at the average value of d.c. This capacitor is called the cathode-bypass capacitor and usually has a capacitive reactance that is small compared with the resistance of the cathode resistor. As a result, it is said to *bypass* the a-c or varying component of the voltage across R_k. Actually, the combination of R_k and C_k acts like an RC filter with a long time constant. Therefore, when the signal causes the plate current to vary, the charge on C_k cannot leak off fast enough to make any considerable difference in the cathode-bias voltage before the current rises to a new peak and recharges C_k.

The value of R_k depends upon the amount of plate current flow and the value of bias voltage required. The value may be calculated by using Ohm's law. For example, suppose that we want to calculate the value of resistance required to provide –8 volts bias for a 6J5 tube, operating with 250 volts on the plate. Looking in the *RCA Receiving Tube Manual*, we find that the plate current (zero signal) is 9 ma. With this information we can find the value of R_k:

$$R_k = \frac{8}{0.009}$$

$$= 889 \text{ ohms}$$

The nearest value of resistor that is commercially available is 910 ohms, which will serve our purpose. In many cases, cathode resistors need have no more than a half-watt power rating.

In some tube other than a triode, the sum of the currents flowing through the resistor must be used when calculating the value of the cathode resistor. For example, in a tetrode or pentode, the screen current must be added to the plate current in order to find the value of R_k. For example, let's assume that we want to find the value of resistance necessary to provide –18 volts grid bias for a 6K6-GT, operating with 250 volts on the screen. Looking in the tube manual, we find that the zero-signal plate current is 32 ma and the zero-signal screen (Grid No. 2) current is 5.5 ma. This makes a total of 37.5 ma flowing through the cathode resistor. Then we find R_k:

$$R_k = \frac{18}{0.0375}$$

$$= 480 \text{ ohms}$$

Sometimes two or more tubes are biased by the same bias resistor. For instance,

Fig. 25-4 shows push-pull triodes with a common cathode resistor. We'll assume that the tubes are operating class A push-pull. Then it will be necessary to add the plate currents (V_1 and V_2) in order to calculate the value of the cathode resistor. Suppose that the tubes are 2A3's operating with 250 volts on the plate. The bias voltage is –45 volts and the plate current is 60 ma. Then we find the cathode resistor:

$$R_k = \frac{45}{0.12}$$

$$= 375 \text{ ohms}$$

The capacity of the cathode bypass capacitor may be determined by applying a simple formula that will serve the needs of any serviceman. The rule says that the reactance of the cathode bypass capacitor at the lowest frequency to be passed should be no more than 1/10 of the resistance of the cathode resistor. For instance, if the resistance of the cathode resistor is 910 ohms and the lowest frequency to be passed is 100 cps, the capacity of the cathode bypass capacitor may be found by using the capacitive reactance formula. The reactance at 100 cps should be no more than 91 ohms. Then:

$$X_C = \frac{1}{2\pi f C}$$

$$C = \frac{1}{2\pi f X_c}$$

$$C = \frac{1}{6.28 \times 10^2 \times 9.1 \times 10}$$

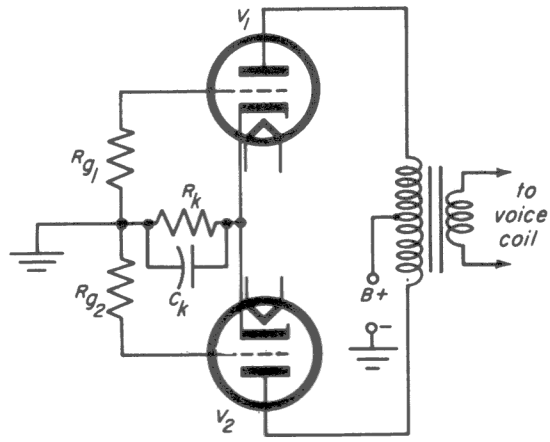
$$= \frac{10^{-3}}{6.28 \times 9.1}$$

• We convert C to μf by multiplying by 10^6:

$$C = \frac{10^{-3} \times 10^6}{57.1}$$

$$= \frac{1,000}{57.1}$$

$$= 17.5 \ \mu f$$



cathode bias for push-pull triodes

Fig. 25-4

Any capacity value found by this method is very conservative. Lower values may be used without affecting the output greatly. The commercially available values nearest to 17.5 μf are 16 or 20 μf. A 25 DCWV capacitor is all that is needed in this example.

Troubles. Before we go further, let's stop and think of the effect that an open cathode resistor, or an open or shorted bypass capacitor would have on the tube operation. First, let's consider the case of an open cathode resistor. Figure 25-5*a* shows the circuit and Fig. 25-5*b* shows the equivalent circuit. Because of the open circuit, the potential on the cathode (measured between cathode and ground) would be practically the same as the potential on the plate. With the potential difference between cathode and plate being practically zero, the tube would not operate. If the bypass capacitor were to become shorted, the resistance between cathode and ground would be zero, with the result that there would be no bias voltage developed. The grid would then operate at

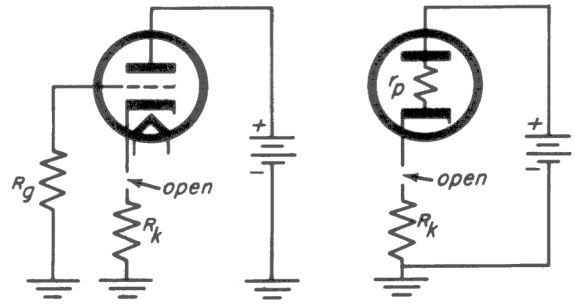


Fig. 25-5

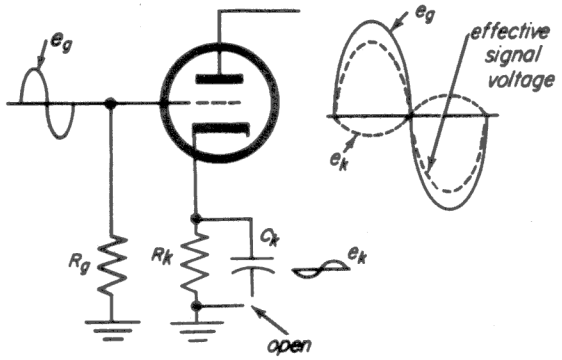


Fig. 25-6

zero bias, which means that on every positive half cycle of the signal the grid would be driven positive, excessive plate current may flow, and the tube may overheat. Also, the output of the tube may be distorted. If the capacitor were to open, the bias voltage developed across the cathode resistor would vary with the signal, which would cause the tube to operate with a varying grid bias. This would result in the bias voltage opposing the signal voltage. As the signal was in its positive half cycle, the bias would be more negative (than the zero-signal bias) and during the negative half cycle of the signal the bias would be less negative. The effect, as shown in Fig. 25-6, is to reduce the effective value of the signal voltage. So an open bypass capacitor usually reduces the output of an amplifier.

Grid-Leak Bias. Another form of self bias, called *grid-leak* or *signal* bias, is illustrated in Fig. 25-7. The capacity of the grid-leak capacitor C_g is high so that its reactance is low compared with the resistance of

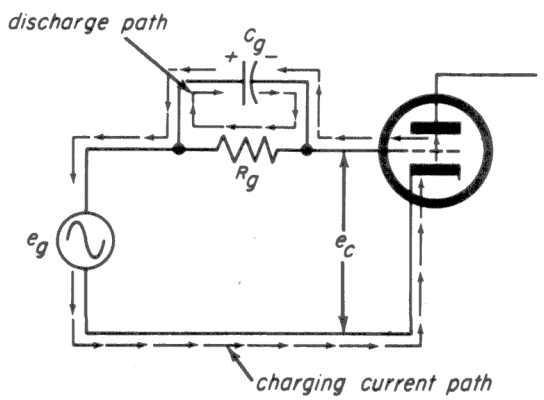
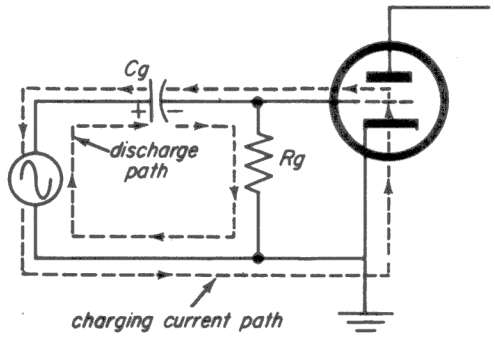


Fig. 25-7

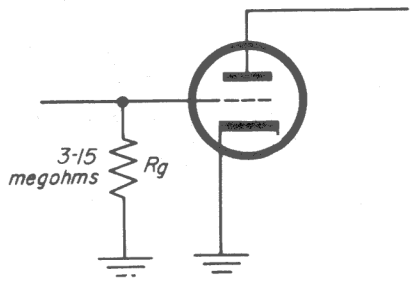


another grid-leak bias circuit

Fig. 25-8

the grid resistor R_g (at the signal frequency). The action of this circuit is as follows. With no signal, the potential difference between the cathode and grid is zero; so, the grid bias is zero. When the signal is applied during the first positive half cycle of the signal, the grid is driven positive, which causes electrons to be attracted to the grid and produces a negative charge on the grid side of the capacitor. As a result, electrons are forced off the opposite plate of the capacitor, and it becomes positively charged. The capacitor charges to the peak value of the signal voltage being applied. The time constant of the R_g–C_g combination is so high that, during the negative cycle, very little of the charge on C_g is allowed to leak across R_g. During the next positive half cycle of the signal, the capacitor is recharged to the peak value of the signal. Thus, a bias voltage is obtained that very nearly equals the peak value of the signal voltage and which makes the grid negative with respect to the cathode. Figure 25-7 shows the charge and discharge paths. Normal values for R_g range from 1 to 3 megohms (although values as high as 5 megohms have been used), and C_g usually has a capacity of about 100 to 250 $\mu\mu$f.

Another arrangement for grid-leak bias is shown in Fig. 25-8. The charging path of this circuit is the same as for the other, while the discharge path is as shown. It is the charge across C_g that provides the bias between grid and cathode. Note that bias (across C_g) and signal voltage are in series with each other and appear between grid and cathode.



contact - potential bias

Fig. 25-9

Contact-Potential Bias. A form of self bias that appears in the first audio stage of many radio and television receivers is called *contact-potential* bias or simply *contact* bias (Fig. 25-9).

Contact bias is developed whether or not a signal is present. During normal passage of electrons from cathode to plate, some electrons are bound to strike the grid. If the electrons are prevented from leaving the grid, the grid will appear to be negative with respect to the cathode. Electrons are prevented from leaving the grid to a great extent by the use of high-value resistors (3-15 megohms). The instantaneous total voltage appearing between grid and cathode is the sum of the signal voltage and the contact-potential bias voltage. A maximum of about 1 volt bias can be obtained by this method.

Certain tubes, such as the 6SQ7 and the 6AT6 are designed to operate satisfactorily with contact bias, and are standard equipment for many receivers.

Bias for Series-Connected-Filament Tubes. Filaments (directly-heated cathodes) of tubes used in battery or three-way portable receivers often obtain grid bias voltage from the difference in potential that exists between the grid and the negative or low end of the tube filament. Fig. 25-10 shows a series string of filaments together with the control-grid and cathode (filament) connections for the output tube. The potential on the filament is +9 volts at the high end and +6 volts at the low end. The bias is taken to be the difference in potential between the 6-volt point and the grid – making the grid negative with respect to the filament by 6 volts.

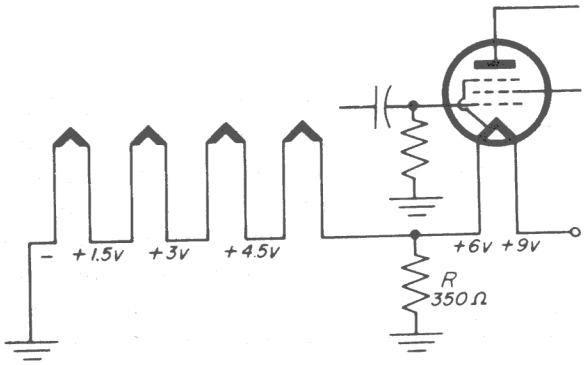


Fig. 25-10

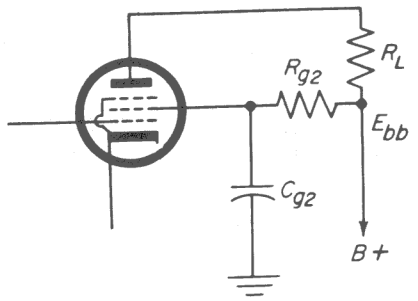


Fig. 25-11

25-2. SCREEN-GRID VOLTAGE SUPPLY.

The screen grid is supplied by the B+ from the power supply. There are several methods used in making this power connection to the screen. That shown in Fig. 25-11 is more often used than any other. The resistor R_{g2} is sometimes called the series *screen resistor*. Its value is determined by the zero-signal screen current and the required screen-grid operating voltage. For example, let's assume that we are going to operate a 6SK7 pentode with 250 volts on the plate and 100 volts on the screen. Looking in the *RCA Receiving Tube Manual*, we find that the zero-signal screen (Grid-No. 2) current is 2.6 ma. We now can find the value of the series screen resistor:

$$R_{g2} = \frac{150}{0.0026}$$

$$= 57{,}700 \text{ ohms (approx)}$$

The nearest commercial value is 56,000 ohms. For many screen grid resistors, a power rating of 1 watt is ample.

The selection of the capacity of the screen bypass capacitor C_{g2} depends upon the lowest frequency to be passed. A rule of

thumb says that the reactance of the screen-bypass capacitor should be no more than 1/10 the resistance of the series screen resistor at the cut-off frequency. For example, in the previous paragraph, we found R_{g2} to be 56,000 ohms. Let's assume that the cut-off frequency is 60 cycles per second. Then:

$$X_{Cg2} = 0.1 \times 56{,}000$$
$$= 5{,}600 \text{ ohms}$$

We now use the capacitive reactance formula:

$$X_C = \frac{1}{2\pi f C}$$

$$C = \frac{1}{6.28 \times 6 \times 10 \times 5.6 \times 10^3}$$

$$= \frac{10^{-4}}{6.28 \times 6 \times 5.6}$$

Multiplying by 10^6 to change to microfarads:

$$= \frac{100}{211}$$

$$= 0.47 \ \mu f$$

In practice, 0.5 μf provides ample bypassing for the lowest audio frequency usually passed in a RC-coupled stage. The capacitor should have a working-volts rating at least equal to E_{bb}.

Figure 25-12 shows another method of connecting the voltage supply to the screen grid. It is used in limiter circuits (FM) and where screen-voltage stability is important. The value of the B+ at point *A* is divided across R_{g2} and R_1. In this circuit, R_1 acts as a bleeder and makes the voltage on the screen grid less dependent on the flow of screen-grid current. To calculate the value of R_{g2} and R_1, it is necessary to know how

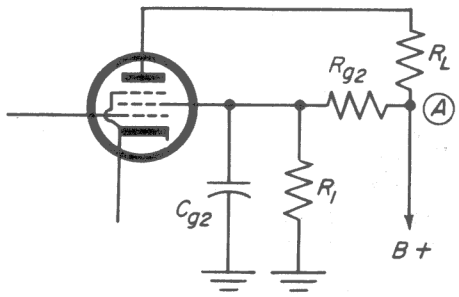


Fig. 25-12

much the bleeder current is. Normal practice is to make the bleeder current equal from 50 to 100% of the no-signal screen grid current. Let's assume that the voltage at *A* (Fig. 25-12) is 200 volts, that 75 volts is required on the screen; that the no-signal screen current is 2 ma, and that the bleeder current is 2 ma also. The total current flowing through R_{g2} is then 4 ma, and the voltage drop across it is 200 less 75 volts or 125 volts. Then:

$$R_{g2} = \frac{125}{0.004}$$

$$= 31{,}250 \text{ ohms}$$

The nearest value commercially available is 33,000 ohms, which will serve our purpose.

Next we find the value of R_1, which has 2 ma flowing through it and 75 volts across it:

$$R_1 = \frac{75}{0.002}$$

$$= 37{,}500 \text{ ohms}$$

We may use either a 36,000-ohm resistor or a 39,000-ohm resistor (the two available values). The capacitor C_{g2} is found in the same manner as before.

25-3. SELECTING OTHER COMPONENTS

The Coupling Capacitor. The low frequency response of the amplifier depends upon the proper selection of a coupling capacitor. The capacitive reactance of the capacitor at the lower cut-off frequency should equal the value of the grid-load resistor R_g. Assuming a cut-off frequency of 100 cps,

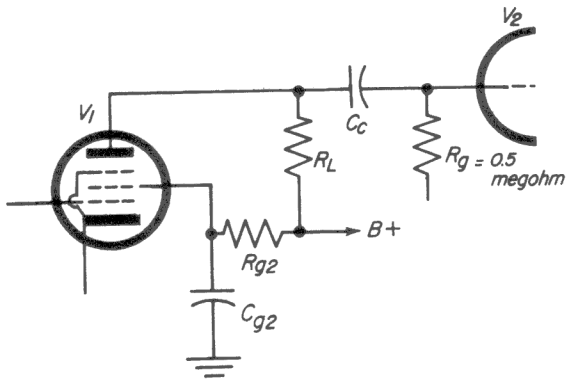


Fig. 25-13

Let's find the value of C_C in Fig. 25-13:

$$X_C = 500{,}000 = \frac{1}{2\pi f C}$$

$$C = \frac{1}{6.28 \times 10^2 \times X_C}$$

$$= \frac{1}{6.28 \times 10^2 \times 5 \times 10^5}$$

$$= 0.003\ \mu f$$

The nearest commercially available value is 0.003 μf, which is as close as we can expect to get. The voltage rating of the coupling capacitor should equal the value of E_{bb}. The capacitor should be of good quality, with a minimum of leakage and with an insulation resistance of 500 megohms or more.

The Grid-Load Resistance. The value of the grid load resistor R_g is usually 1 to 5 times that of the plate load of the previous stage. However, the amount of resistance that may be applied to the grid circuit is limited by the design of the tube and the completeness of its vacuum. The design affects it in that, if the grid is close enough to the cathode, it may become hot enough to emit electrons. The completeness of the vacuum determines how much gas may still be present in the tube. The more gas that remains, the greater is the possibility that gas ions will strike the grid and cause it to emit electrons. In either case, a current flow from grid to cathode may result. When this occurs, a positive voltage appears on the grid and causes the plate current to rise. Under these conditions, the plate current may become great enough so that the tube is destroyed.

Typical values for R_g range from 0.25 to 1.0 megohms for most tubes operating with self bias. When tubes are operated with fixed bias, the upper limit is about 0.5 megohm. For power tubes that dissipate more than 10 watts, the maximum is 0.5 megohm with self bias and 0.1 megohm with fixed bias. Where the tube manual suggests a maximum value for the grid-load resistor, that value should not be exceeded.

25-4. USING RESISTANCE-COUPLED AMPLIFIER CHARTS.

A section entitled *Resistance-Coupled Amplifiers* appears in the back of your *RCA Receiving Tube Manual.* In this section you will find charts containing operating data for about 50 tubes commonly used in R-C coupled amplifiers. For most tubes, cathode bias and, (where applicable) series screen resistors are part of the design data. Before you use this section, we suggest that you read the introductory material that appears before the charts. You will find that some of the abbreviations for tube parameters used in this section differ from those that we have been using and which were listed in Appendix A in Lesson 23. While the abbreviations that we have been using agree with the latest standards, you will find that some different abbreviations are still in use. For example, Fig. 25-14 *a* and *b* show that the plate-load resistor, which we have been calling R_L, is labeled R_p; and the coupling capacitor (C_c) is labelled C. You'll note, too, that the coupling capacitor is called the *blocking capacitor* – a term often applied to it, because it blocks d.c. from the plate circuit from reaching the following grid. The output voltage (the peak signal voltage that appears on the following grid) is abbreviated E and the voltage gain is labelled $V.G.$ It is important that you understand the meaning of these abbreviations because they appear as column headings in the charts. A brief explanation of the charts and their application follows.

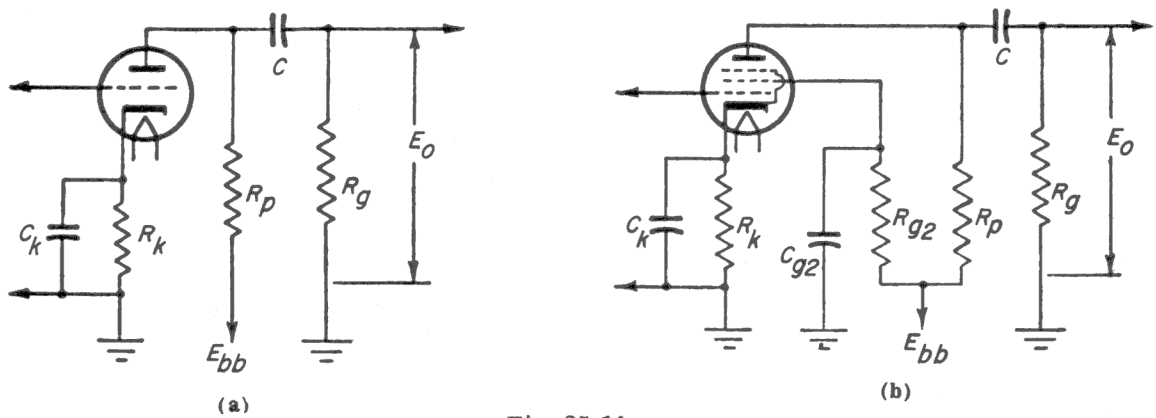


Fig. 25-14

Figure 25-15 reproduces one of the charts that appear in your tube manual. It applies to seven tubes, three of which are single triodes and four of which are dual triodes. The tubes are listed in the left margin. The dots that mark the four triodes refer to a footnote that appears at the bottom of the page, which indicates that the values given in the chart are for single sections of the dual triodes. So, for each section, one set of resistors and capacitors is required.

In the first column, under the heading E_{bb}, three different values of plate-supply voltage are given. The second column lists different values of plate-load resistance in

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13

6F8-G•
6J5
6J5-GT
6SN7-GT•
6SN7-GTA•
12J5-GT
12SN7-GT•

E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.047	0.047	–	1870	–	3.1	0.063	14	13
		0.1	–	2230	–	2.5	0.031	18	14
		0.22	–	2500	–	2.1	0.016	20	14
	0.1	0.1	–	3370	–	1.8	0.034	15	14
		0.22	–	4100	–	1.3	0.015	20	14
		0.47	–	4800	–	1.1	0.006	23	15
	0.22	0.22	–	7000	–	0.80	0.013	16	14
		0.47	–	9100	–	0.65	0.007	22	14
		1.00	–	10500	–	0.60	0.004	25	15
180	0.047	0.047	–	1500	–	3.6	0.066	33	14
		0.1	–	1860	–	2.9	0.055	41	14
		0.22	–	2160	–	2.2	0.015	47	15
	0.1	0.1	–	2750	–	1.8	0.028	35	15
		0.22	–	3550	–	1.4	0.015	45	15
		0.47	–	4140	–	1.3	0.007	51	16
	0.22	0.22	–	5150	–	1.0	0.016	36	16
		0.47	–	7000	–	0.71	0.007	45	16
		1.00	–	7800	–	0.61	0.004	51	16
300	0.047	0.047	–	1300	–	3.6	0.061	59	14
		0.1	–	1580	–	3.0	0.032	73	15
		0.22	–	1800	–	2.5	0.015	83	16
	0.1	0.1	–	2500	–	1.9	0.031	68	16
		0.22	–	3130	–	1.4	0.014	82	16
		0.47	–	3900	–	1.2	0.0065	96	16
	0.22	0.22	–	4800	–	0.95	0.015	68	16
		0.47	–	6500	–	0.69	0.0065	85	16
		1.00	–	7800	–	0.58	0.0035	96	16

Fig. 25-15

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E_{bb}	R_p	R_g	R_{g2}	R_k	C_{g2}	C_k	C	E_o	V.G.
90	0.1	0.1	0.29	820	0.09	8.8	0.02	18	41
		0.25	0.29	880	0.085	7.4	0.016	23	68
		0.5	0.31	1000	0.075	6.6	0.007	28	70
	0.25	0.25	0.69	1680	0.06	5.0	0.012	16	75
		0.5	0.92	1700	0.045	4.5	0.005	18	93
		1.0	0.82	1800	0.04	4.0	0.003	22	104
	0.5	0.5	1.5	3600	0.045	2.4	0.003	18	91
		1.0	1.7	3800	0.03	2,4	0.002	22	119
		2.0	1.9	4050	0.028	2:35	0.0015	24	139
180	0.1	0.1	0.29	760	0.10	9.1	0.019	49	55
		0.25	0.31	800	0.09	8.0	0.015	60	82
		0.5	0.37	860	0.09	7.8	0.007	62	91
	0.25	0.25	0.83	1050	0.06	6.8	0.001	38	109
		0.5	0.94	1060	0.06	6.6	0.004	47	131
		1.0	0.94	1100	0.07	6.1	0.003	54	161
	0.5	0.5	1.85	2000	0.05	4.0	0.003	37	151
		1.0	2.2	2180	0.04	3.8	0.002	44	192
		2.0	2.4	2410	0.035	3.6	0.0015	54	208
300	0.1	0.1	0.35	500	0.10	11.6	0.019	72	67
		0.25	0.37	530	0.09	10.9	0.016	96	98
		0.5	0.47	590	0.09	9.9	0.007	101	104
	0.25	0.25	0.89	850	0.07	8.5	0.011	79	139
		0.5	1.10	860	0.06	7.4	0.004	88	167
		1.0	1.18	910	0.06	6.9	0.003	98	185
	0.5	0.5	2.0	1300	0.06	6.0	0.004	64	200
		1.0	2.2	1410	0.05	5.8	0.002	79	238
		2.0	2.5	1530	0.04	5.2	0.0015	89	263

19

6SJ7
6SJ7-GT
12SJ7

Fig. 25-16

megohms, labelled R_p. The third column gives the resistances in megohms of the grid resistor R_g for the *following* stage. The next heading is for R_{g2}, the screen resistor. Triodes, of course, have no screen grids, so this column is left blank. The next column gives values in ohms of the cathode bias resistor, R_k. The next refers to the screen-bypass capacitor, which is blank because the chart refers to triodes. The following column gives the value of the cathode-bypass capacitor, C_k, in microfarads. The next column gives values of capacity in microfarads for the coupling capacitor, which is labelled C. The output signal voltage (input to the following grid) is labelled E_o and is given in volts. The voltage gain *(V.G.)* is shown in the last column.

Here's how we might use this chart. Suppose that E_{bb} is 180 volts, and that with an input signal of 3 volts peak we use 45 volts peak to drive the grid of the following tube. Under the E_o column and in the 180-volt E_{bb} section, we find that 45 volts (peak) appears twice. In one case, the voltage gain is shown to be 15. Dividing E_o by $V.G.$ (45 by 15), we find that the input signal should be 3 volts (peak). This meets our requirements. Therefore, the plate-load resistor should be 0.1 megohm; the grid resistor of the following stage, 0.22 megohms; the cathode resistor, 3,550 ohms; the cathode bypass, 1.4 μf; and the coupling capacitor, 0.015 μf.

Figure 25-16 reproduces a typical pentode amplifier chart from the tube manual. Here, in addition to the values given for a triode, are the values for the screen resistor and bypass capacitor. The resistance of the screen resistor is given in megohms and of the screen bypass capacitor in microfarads. It is used in the same way as are the charts for the triodes.

25-5. DESIGNING A SIMPLE TWO-STAGE AUDIO AMPLIFIER

In designing an amplifier of two or more stages, we start from the output and work back to the signal input, which may be a microphone, a radio-detector stage, or a phono pickup. Here we show the steps normally taken in designing a simple two-stage audio amplifier.

Let's start off with a loudspeaker that can handle 10 watts of electrical power without distortion, and which has a voice coil rated at 8 ohms. Our next step is to find the power-amplifier tube or tubes that can supply this much power. At this point we must know how much distortion we can tolerate in the output. If distortion is a secondary consideration, we can obtain the necessary power from a 6L6 or 6L6-G beam power tube. Referring to the Typical Operation chart for the 6L6, we find that, operating with fixed bias, 350 volts on the plate, and 250 volts on the screen, we can obtain 10.8 watts of audio power. However, under these conditions, the total harmonic distortion is 15 percent, which is usually considered too high for a radio, television, or phono amplifier.

However, let's assume that we can tolerate 15 percent of harmonic distortion. Our next step is to determine the value of the components used in the power amplifier stage. The tube manual tells us that the plate-load resistance for the conditions under which we plan to operate the tube is 4,200 ohms. The output transformer Fig.25-17 must match the loudspeaker to the plate circuit; it must look like 4,200 ohms in the primary and 8 ohms in the secondary. The turns radio is therefore:

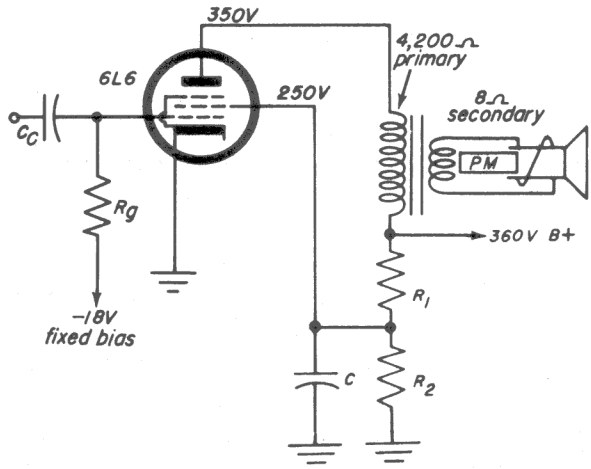

Fig. 25-17

$$\text{Turns ratio} = \frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}} = \sqrt{\frac{4{,}200}{8}}$$

$$= \sqrt{525}$$

$$= 22.9$$

The turns ratio is 22.9 to 1; which means that, for every turn in the secondary, there are 22.9 turns in the primary. Because of the possibility of magnetic saturation, a good quality transformer, one with high primary inductance, should be chosen.

Next, we supply voltage to the screen grid. Usually, when there is little difference between zero-signal and maximum-signal screen currents, a series-dropping screen resistor may be used to supply the screen voltage. However, this method should not be used when beam-power and power-pentode tubes are operated so that there is a large change between zero-signal and maximum-signal screen currents. The tube manual shows that the zero-signal screen current of the 6L6, operating under the conditions that we selected, is 2.5 ma, and the maximum-signal current is 7 ma. Therefore, we must use the voltage divider method to supply our screen voltage or obtain it from another power source. We'll use the voltage divider method. The value of the voltage-divider resistors R_1 and R_2 depend upon the total current drawn from the voltage divider at 250 volts. This, in turn, depends upon the amount of current used by any other tubes that are being supplied with 250 volts. Without this information, we cannot calculate the values of R_1 and R_2. Let's assume that the total current drawn at 250 volts is 12.5 ma (including the 2.5 ma zero-signal screen current) and that the bleeder current is 10 ma. Then the total current flowing through R_1 is 22.5 ma.

However, we still cannot calculate the value of R_1 until we know the value of the plate-supply voltage, E_{bb}. We know that it will be very close in value to the plate voltage, which is 350 volts. The actual value depends upon the resistance of the output transformer primary, which in turn depends upon the particular transformer that is chosen. We can get an approximate value – one that will be very close to the final value – by assuming an E_{bb} of 360 volts. The difference between E_{bb} and the screen voltage is 110 volts (360-250). Now we can find the value of R_1:

$$R_1 = \frac{110}{0.0225}$$

$$= 4{,}890\ \Omega$$

The nearest commercial value is 5,000 ohms. The amount of power dissipated in the resistor is about 2.5 watts, so R_1 should be rated at about 5 watts.

Only the 10 ma of bleeder current flows through R_2, which is found as follows:

$$R_2 = \frac{250}{0.01}$$

$$= 25{,}000 \text{ ohms}$$

A resistor of this value may be obtained commercially. R_2 dissipates 2.5 watts, too, and should be rated at 5 watts.

The value of the filter capacitor C ranges between 4 and 20 μf. It should be rated at 450 WVDC.

Because we are using fixed bias, the grid load resistor R_g should have a value no higher than 0.1 megohm, as recommended for the 6L6 in the tube manual under *Installation And Application.*

Our next problem is to select the tube for our driver stage.

The tube we select must be able to supply a peak signal voltage of 18 volts, which is the peak a-f grid voltage recommended for the 6L6 under *Typical Operation* as a single class A_1 amplifier. However, in addition to knowing the output voltage of our driver tube, we must know what the input signal voltage will be so that we may know how much voltage gain we must look for in the tube. Let's assume that the peak input voltage is 2 volts. The voltage gain must be:

$$V.G. = \frac{E_o}{E_{in}}$$

$$= \frac{18}{2}$$

$$= 9$$

If possible, we'll use a triode, so we'll look first among the triodes for a suitable tube. The best place to look is in the R-C amplifier charts in the back of our RCA Receiving Tube Manual. First we look for 9 under the *V.G.* column and for 18 in the E_o column. Several tubes could serve our purpose. Among these is the 6C5, which we find is used principally for renewal purposes. However, we find that we can use the 6J7, connected as a triode, which is rated to give an E_o of 17 volts with a voltage gain of 9. This is close enough for our purposes. The chart recommends an E_{bb} of 90 volts, a plate-load resistor of 0.05 megohm, and a grid resistance for the following stage of 0.1 megohm, which, you recall, is the maximum we may use, a cathode resistor of 3,400, a cathode-bypass capacitor of 1.62 μf, and a coupling capacitor of 0.025 μf. The complete schematic drawing for our two-stage amplifier is shown in Fig. 25-18.

Alternate Amplifier. If we cannot tolerate so much distortion as the 6L6 produces when delivering 10 watts of audio power, we must look for some other power amplifier to deliver the necessary power. No single tube among those listed in the RCA Receiving Tube Manual can deliver the power that we need and keep the harmonic distortion within ac-

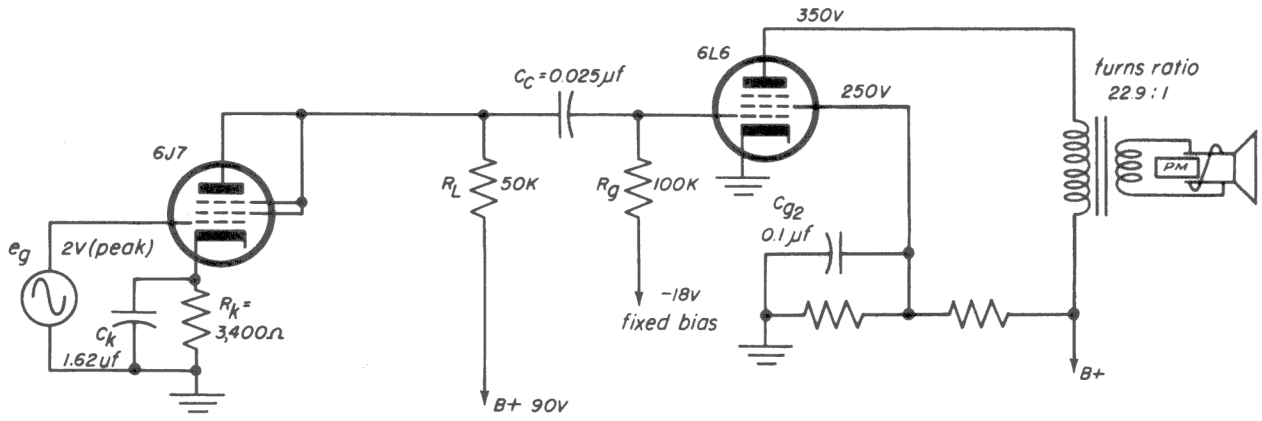

Fig. 25-18

ceptable limits. Therefore, we had better look for a push-pull combination to give us the power we need with minimum distortion.

We might select push-pull triodes, such as 2A3's. We would then need a very high driving voltage from the previous stage. If we use a pair of pentodes or beam-power tubes, we need much less driving voltage because of the greater power sensitivity of such tubes. Among the tubes that we might choose, let's select a pair of 6F6's, which, operated class A, deliver 11 watts with 4 percent total harmonic distortion (Fig. 25-19). Using fixed bias, each tube is operated with 315 volts on the plate and 285 volts on the screen. The peak control-grid-to-control-grid signal voltage is 48 volts, or 24 volts for each grid. The plate-to-plate load is 10,000 ohms, so the output transformer must look like 10,000 ohms in the primary and 8 ohms in the secondary. The turns ratio is:

$$\text{Turns ratio} = \frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}} = \sqrt{\frac{10{,}000}{8}}$$

$$= \sqrt{1{,}250}$$

$$= 35.4$$

So the primary-to-secondary turns ratio is 35.4 to 1. Because the transformer provides a load for two tubes in push-pull, its primary is center-tapped.

The value of the series screen resistor R_{g2} depends on the value of E_{bb}, which in turn depends on the resistance of the output-transformer primary. However, as was the case with the single-ended amplifier discussed earlier in this lesson, we calculate the approximate value of the screen resistor by assuming the value of E_{bb} that is slightly higher than the plate voltage E_b. Let's assume an E_{bb} of 325 volts. The voltage drop across the screen resistor is 325-285, or 40 volts and the zero-signal screen current for two tubes is 12 ma. Then:

$$R_{g2} = \frac{40}{0.012}$$

$$= 3{,}330 \text{ ohms}$$

The nearest value commercially available is 3,300 ohms, which will serve our needs.

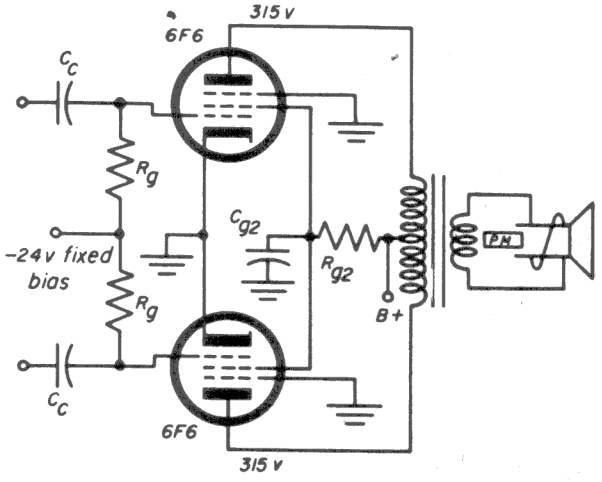

Fig. 25-19

The value of the screen bypass capacitor is found in the same way as was discussed earlier in this lesson. Its reactance at cutoff should equal 1/10 the resistance of the screen resistor. Assuming cutoff to be 100 cps, we find the capacity:

$$C_{g2} = \frac{1}{2\pi f X_c}$$

$$= \frac{1}{6.28 \times 10^2 \times 3.3 \times 10^2}$$

$$= \frac{1 \times 10^{-4}}{6.28 \times 3.3}$$

$$= \frac{100 \times 10^{-6}}{6.28 \times 3.3}$$

$$= 4.83 \ \mu f$$

A capacitor of either 4 or 8 μf, with a working voltage of 450 volts may be used. The higher capacity may be needed if the hum voltage (ripple) is excessive.

The grid resistors R_g are equal in value. Because the tubes are operating with fixed bias, the value of R_g cannot be as high as it might be for cathode bias; therefore, the maximum value of resistance should not exceed 0.1 megohm.

Our next step is to select the tube or tubes for our driver stage. Unless we want to spend a lot of money for a high-quality interstage transformer, we are better off using a phase inverter to drive our output tubes. For minimum distortion, we select triodes for our driver tubes. The tubes may be separate or together in one envelope. Referring to the *Resistance-Coupled Amplifier Charts* in the tube manual, we look for a tube that has an output of 24 peak-signal volts with a voltage gain of 12. We find that we can use either two 6C4's or one 12AU7 dual triode. While the 12AU7 is rated at 12.6 heater volts, the heater is center-tapped so that both sections may be connected

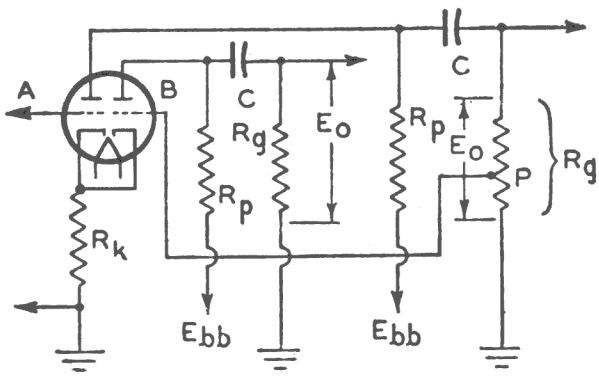

Fig. 25-20

in parallel and operated on 6.3 volts. The cost of two 6C4's is about the same as the cost of one 12AU7, so price is not a factor. However, to conserve space, we will choose the 12AU7.

Figure 25-20 shows the components of the phase inverter stage labelled as they are in the R-C chart. The chart recommends an E_{bb} of 180 volts, a plate load of 0.1 megohm, a grid resistance of 0.1 megohm (for each of the output control grids), and a cathode resistor of 2,000 ohms. However, instead of using separate cathode resistors, we plan to use one resistor for both tubes, which means that twice the current flows through the cathode resistor. Therefore, the value of R_k is halved in order to produce the same value of bias. So R_k becomes 1,000 ohms. It might appear that the value of the cathode-bypass capacitor should then become twice that given in the chart (so that its reactance may have the same proportion to R_k as was determined for a single tube). However, the out-of-phase signal currents cancel through the common cathode resistor. To reduce distortion due to possible unbalance, a value of 2 μf should be sufficient. But, we may find that this value should be raised to 8 or 10 μf in order to reduce hum. The coupling capacitor is 0.032 μf; for which we might use either a 0.03- or 0.035-μf capacitor rated at a minimum of 400 WVDC.

The selection of the point P on the grid resistor that receives the output of triode A is determined by the voltage gain of the triode. The voltage gain of each triode section of the 12AU7 is 12, so the section of the grid resistor between the Point P and the low end of the

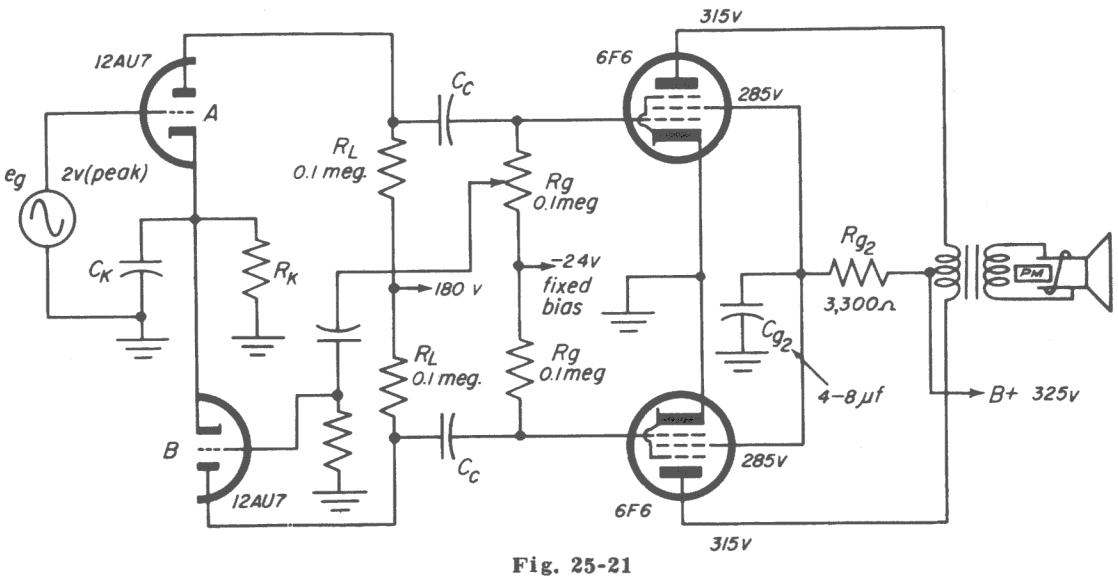

Fig. 25-21

resistor should be 1/12 of the total grid resistance.

The complete schematic drawing of the two stages of audio amplification is shown in Fig. 25-21

25-6. APPLYING NEGATIVE FEEDBACK

As you know, the output of an audio amplicontains not only the wanted amplified signal; it contains harmonic distortion, frequency distortion, hum, and noise, too. By applying degeneration or negative feedback, the frequency response may be improved and much of the unwanted distortion and hum eliminated. (You recall that negative feedback was discussed in the lesson on voltage amplifiers). Now let's see how negative feedback may be applied to an audio-amplifier in order to improve its response.

Let's first consider the improvement of frequency response. Suppose that we have an amplifier that has the frequency response like that of the solid curve shown in Fig. 25-22. With negative feedback applied in sufficient quantity, the frequency flattens out and looks like the lower dotted curve. Note that while the output voltage has been reduced, the frequency response has widened and the bump at about 10,000 cps has almost disappeared. If the input signal is now raised to bring the output voltage up to the previous level (the upper dotted curve), the amplifier retains the same level of frequency response as the lower dotted curve.

We say that negative feedback has this effect. Let's see why it is so. Examine the frequency response curve for operation without feedback. Low frequencies are not amplified as much as the middle frequencies. Also, the output transformer seems to rise at about 10,000 cps, so there is a resonant bump in the curve. Beyond about 20,000 cps the response drops off rapidly. This means that any low- or high-frequency voltage fed back to the input will not be as great as the mid-frequency or 10,000-cycle voltage, because the voltage at each frequency is in proportion to the amount of voltage of the same frequency that appears in the output. Therefore, the amount that the feedback voltage subtracts from the input signal voltage depends upon the frequency. Very little

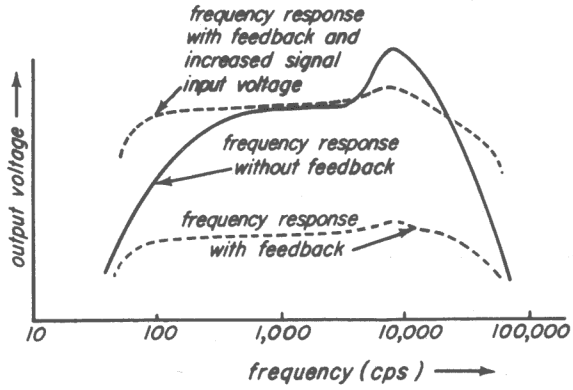

Fig. 25-22

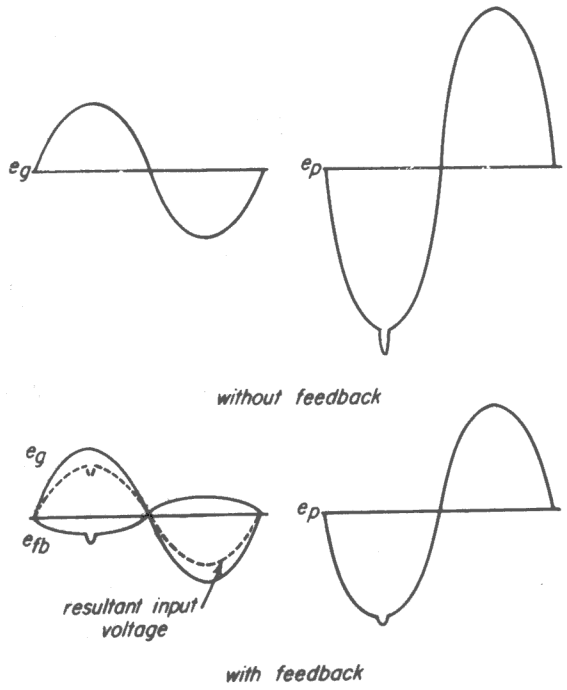

Fig. 25-23

of the low or high frequency voltages is subtracted from the input; a greater amount is subtracted from the middle-frequency input; and the greatest amount from the voltage of the frequencies around 10,000 cps.

Negative feedback also tends to decrease distortion, hum, and noise in much the same way. Figure 25-23 shows a distorted waveform and the effect that negative feedback has upon the output waveform. Let's examine these waveforms and see what they can tell us. The first one shows that the input signal on the grid is a pure sine wave. The second one shows that, without feedback, one alternation of the output voltage is distorted. Next we see the original signal voltage again, marked e_g, with the feedback voltage e_{fb} opposing it. The feedback voltage subtracts from the original signal voltage and produces a resultant voltage that actually appears at the grid of the tube. With such an input signal, the output plate voltage is shown to have decreased and, at the same time, to have lost a measure of its distortion As the illustrations show, complete cancellation of harmonic distortion is not possible. However, a considerable reduction in the harmonic distortion can be obtained. On the other hand, complete cancellation of hum is theoretically, if not always practically, possible. If 60-cycle or 120-cycle hum voltage is fed back in sufficient quantity and opposite phase, there should be little or no hum in the output.

Factors Concerning Negative Feedback. There are several important factors that we must consider when applying negative feedback to an audio amplifier. Some of these are discussed in the following paragraphs.

First of all, we must consider whether or not there is anything much to be gained from the application of negative feedback. For example, negative feedback is seldom applied to push-pull 2A3's because the distortion present in the output is already quite low (provided that the tubes are operated within reasonable limits). When negative feedback is applied to such tubes, it effectively reduces the voltage gain of the stage. Therefore, it is necessary to increase the driving voltage in order to obtain the same power output that is obtained without feedback. However, negative feedback may profitably be applied to beam-power tubes, which normally introduce more harmonic distortion, than to triodes. Beam-power tubes provide full-power output with a relatively low-driving voltage. Of course, it is necessary to increase the driving voltage when feedback is applied, but the increase normally doesn't amount to much in the case of beam-power tubes. From this, you can see that it is necessary to know how much negative feedback will improve the output, how much more driving voltage is necessary to obtain the same power output as is obtained without feedback, whether or not the driving stage can supply this extra voltage by adjusting the operating condition or whether or not an extra stage of voltage amplification is necessary, and then to determine whether or not the improvement in response is worth the cost.

The requirements for negative feedback are:

1. The feedback voltage must be 180 degrees out of phase with the signal voltage at the point where the feedback voltage is introduced.

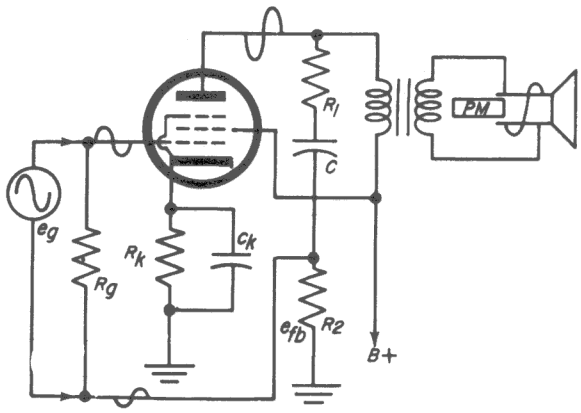

Fig. 25-24

2. The feedback voltage must be of sufficient amplitude to be effective in reducing the unwanted distortion or hum voltage.

3. The feedback voltage must have as one of its components the voltage that you are trying to reduce.

4. If the same power output is required after feedback has been added as exists without feedback, the driving stage must supply a greater driving voltage with the same tube or tubes, with a change in tube or tubes, or with the addition of another stage of amplification inserted before the driving stage.

Figure 25-24 shows a typical audio-power amplifier to which negative feedback has been added. We know that a tube produces a 180-degree phase difference between the signal voltage on the control grid and the amplified signal voltage across the plate load. The entire amplified signal voltage appears across the output transformer primary and across the two series resistors, R_1 and R_2 (the capacitor C only acts to block the d.c. and offers practically no opposition to the audio signal voltage). The amount of negative feedback depends upon the ratio:

$$\text{feedback} = \frac{R_2}{R_1 + R_2}$$

So the greater R_2 is, the greater is the portion of the amplified signal voltage that is fed back out of phase with the signal input.

Feedback voltage obtained from the output transformer helps to reduce the types of distortion already discussed. In addition, it helps to correct a condition that originates in the load. Because the impedance offered by the voice coil of the loudspeaker is not constant, but varies with frequency, the load on the output tube or tubes varies with frequency. As a result, the amount of amplified signal voltage that appears across the primary of the output transformer varies with frequency. With sufficient negative feedback, such nonlinearity is greatly reduced.

Sometimes negative feedback is voltage returned from the output transformer secondary to the input of the driver stage (Fig. 25-25). The illustration shows that a separate secondary winding is used on the output transformer to obtain the feedback voltage.

There are other methods used in obtaining feedback voltage from the output secondary, but this method is probably the best. One point to remember is that, while large currents flow in the voice coil, the voltage across the voice-coil winding of the output transformer is usually low, so that obtaining sufficient feedback voltage from this winding presents a problem. We can check the phase of this feedback voltage (with reference to the signal voltage at the grid of V_1) by noting the phase changes that occur between the V_1 grid and the output transformer feedback secondary. The signal voltage on the control grid of V_2 is 180 degrees out of phase with that on the grid of V_1. The phase difference is 360 degrees at the primary of the output transformer and it is 540 degrees at the feedback secondary of the transformer (a transformer

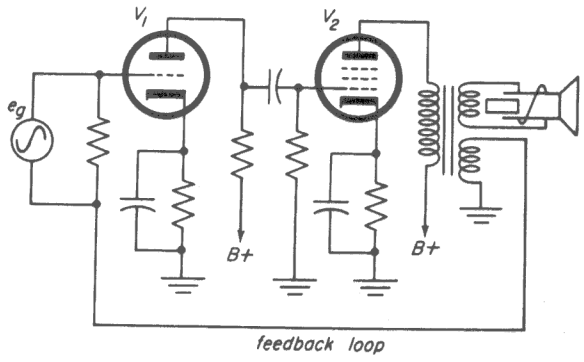

Fig. 25-25

causes a phase change of 180 degrees). A phase change of 360 degrees brings the voltage back in phase. Therefore, we subtract 360 from 540 and get the effective phase change, 180 degrees.

Negative feedback or degeneration is sometimes obtained by omitting the cathode bypass capacitor (Fig. 25-26). As you learned in an early part of this lesson, without the cathode bypass capacitor, the bias voltage varies when a signal is applied to the tube, and this varying bias opposes the signal voltage, thus causing degeneration. This method of applying degeneration usually reduces harmonic distortion and is effective in correcting frequency response. Omitting the cathode bypass capacitor in a push-pull output stage when both tubes use a common cathode resistor does not normally

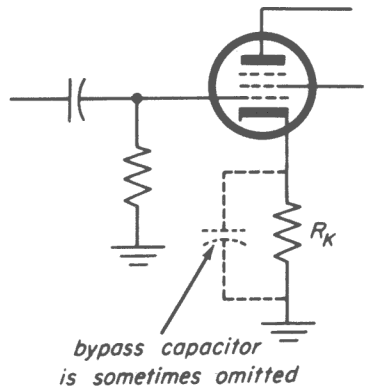

Fig. 25-26

cause degeneration. When the current in one tube decreases, the current in the other tube increases, so the total current flowing through the cathode resistor is constant. For that reason, some push-pull power amplifier stages do not use cathode bypass capacitors at all.